Time calibration, monitoring and performance of the ATLAS Tile Calorimeter in Run 2

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Abstract

The Tile Calorimeter (TileCal) is the central hadronic calorimeter of the ATLAS experiment at the Large Hadron Collider (LHC). It is made of steel plates acting as absorber and scintillating tiles as active medium. The TileCal response is calibrated to electromagnetic scale by means of several dedicated calibration systems. The accurate time calibration is important for the energy reconstruction, non-collision background removal as well as for specific physics analyses. The initial time calibration using so-called splash events and subsequent fine-tuning with collision data are presented. The monitoring of the time calibration with laser system and physics collision data is discussed as well as the corrections for sudden changes performed still before the recorded data are processed for physics analyses. Finally, the cell time resolution as measured with jet events in Run 2 is presented.

Keywords: ATLAS experiment, hadronic calorimeter, Tile Calorimeter, time calibration, timing monitoring

1. The hadronic Tile Calorimeter

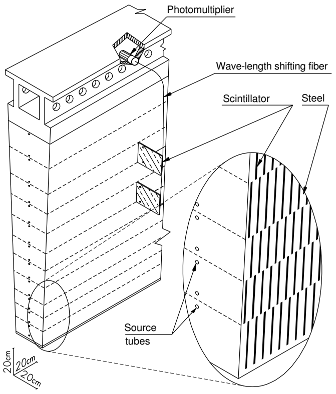

Figure 1: The mechanical assembly and the optical readout of the Tile Calorimeter module [1].

The Tile Calorimeter (TileCal) is the central ($|\eta| < 1.7$) hadronic calorimeter of the ATLAS experiment [2] at the Large Hadron Collider [3]. The TileCal provides data for reconstruction of jets, hadronically decaying tau-leptons, hadrons, and missing transverse energy. Besides that, it assists in muon identification. The TileCal is a sampling detector composed of alternating layers of steel absorber and scintillating plastic tiles.

Charged particles passing through the tiles produce light transmitted by wavelength shifting fibers to photomultiplier tubes (PMTs). The TileCal comprises 5182 cells azimuthally arranged in 64 modules (Figure 1). A cell is typically read out by two PMTs (channels). The signal is passed to front-end electronics for shaping, amplification, and digitization. Depending on the energy of a particle passing through, the high gain (HG) or low gain (LG) amplified signal is reconstructed, where the amplification ratio is 1:64. The Optimal Filtering algorithm [4] reconstructs the signal amplitude and phase based on seven digitized samples (Figure 2). The deposited energy is evaluated as the reconstructed amplitude multiplied by calibration coefficients.

2. The time calibration

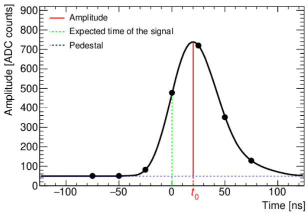

Figure 2: The reconstruction of the signal pulse with a non-zero phase.

The time calibration adjusts the phase of the sampling clock to the peak of the signal produced by the traversing particle. With perfect time calibration, the signal phase $t \sim 0$ ensures a proper reconstruction of the signal amplitude. Moreover, time measurements are used for time-of-flight studies and removal of non-collision background.

Before Run 2 physics collisions, the time calibration was performed with high-energy muons in splash events. Time calibration constants were obtained as the average reconstructed time and corrected for times-of-flight.

The final calibration was derived with first proton-proton collision data. Time calibration constants were estimated as a Gaussian mean of the time distribution in jet-associated cells. Channels with 2 GeV $< E_{\mathrm{ch}} <$ 4 GeV were exploited for the HG calibration. The LG calibration was achieved by correcting the HG calibration set for faster signal propagation in a LG as well as the mean time on dependency on measured energy. In 2016–18, the LG calibration was fine-tuned based on timing measured in high-energy channels (15 GeV $< E_{\mathrm{ch}} <$ 50 GeV).

Several electronic components were replaced during maintenance campaigns, and time constants in affected channels were adjusted with respect to the time offsets seen in laser events [5].

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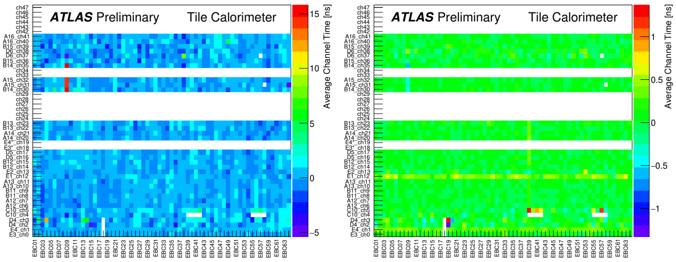

Figure 3: The reconstructed time in each TileCal readout channel averaged over run, before (left) and after (right) time correction applied [6].

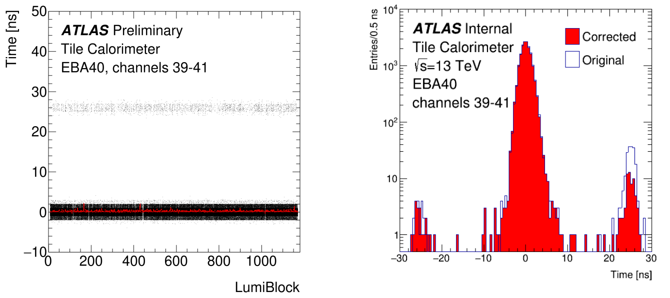

Figure 4: A fraction of events with the bunch-crossing time offsets (+25 ns) observed in laser (left) and jet (right) events [6].

3. The time monitoring

The time calibration was monitored with two independent methods: by the estimation of the mean time in jet events during proton-proton collisions, and by measuring the responses to laser pulses emitted during empty bunch crossings.

Time offsets above 3 ns were identified and promptly addressed before full ATLAS data processing. The readout gains with time instabilities were recalibrated (Figure 3) or vetoed for timing-sensitive studies. As timing stability was continuously monitored in laser events, time calibration biases were corrected in affected Luminosity Blocks (LBs) exclusively.

Majority of time calibration fluctuations were traced to electronic components problems. Thus, damages of a 3-in-1 card due to overcurrent resulted in changes of the reconstructed phase and amplitude in the related channels. Fractions of events with bunch-crossing time offset (Figure 4) were observed in groups of three channels (connected to the same Data Management Unit). Due to improved electronics stability, only a few dozens of "time jumps" (changes of time settings for six channels related to the same digitizer) were observed in Run 2.

The time calibration was revised at the end of data-taking year to precise timing conditions for ATLAS data reprocessing.

4. The timing performance

The TileCal time performance was stable during Run 2. Fluctuations of the mean time are within 0.05 ns (Figure 5) between years. The mean cell time depends on the deposited energy due to different dynamics for fast and slow components of hadronic showers.

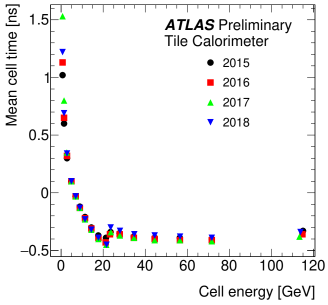

Figure 5: The mean time dependency on the cell energy in Run 2 [6].

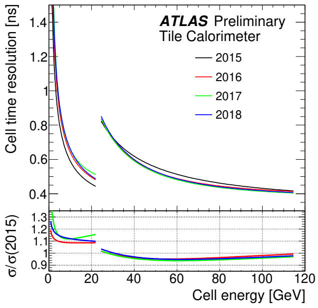

Figure 6: The time resolution as a function of the deposited cell energy measured per Run 2 data-taking year [6].

The time resolution raised by ~10% in cells with $E_{\text{cell}} < 20$ GeV due to higher pile-up since 2016 (Figure 6). In cells with $E_{\text{cell}} > 4$ GeV, the time resolution is below 1 ns. The improvement of the LG calibration resulted in a 5% better resolution in 2016–18 (Figure 6) despite higher pile-up. The LG time resolution constant term approaches ~ 0.4 ns.

5. Conclusions

Each year in Run 2, the initial (final) time calibration was based on splash or laser events (jet events from *pp* collisions). The time calibration was monitored in laser as well as jet events. The time resolution below 1 ns was achieved in LG.

Acknowledgements

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